Session VIII. Airborne LIDAR

N91-24142

Continuous Wave Laser
Dr. Loren Nelson, OPHIR Corporation

THIRD ANNUAL MANUFACTURER'S AND TECHNOLOGISTS' AIRBORNE WIND SHEAR REVIEW BRIEFING

NASA LANGLEY RESEARCH CENTER
October 17, 1990

CONTINUOUS WAVE LASER FOR WIND SHEAR DETECTION

Dr. Loren Nelson
OPHIR Corporation
3190 S. Wadsworth Blvd.
Lakewood, CO 80227
(303) 986-1512

ABSTRACT

We present results of our development of a continuous-wave heterodyne carbon dioxide laser which has wind-shear detection capabilities. This development was sponsored by the FAA under their SBIR program under contract number DTRS-57-87-C-00111.

The goal of the development was to investigate the lower cost CW (rather than pulsed) lidar option for look-ahead wind shear detection from aircraft. The device also has potential utility for ground based wind-shear detection at secondary airports where the high cost ($6,000,000) of a Terminal Doppler Weather Radar (TDWR) system is not justifiable. The CW-Lidar system presented here was fabricated for a hardware cost of less than $100,000.

Details of the design and fabrication of the OPHIR CW 10.6μ heterodyne doppler lidar wind shear detector are presented. Shot noise limited heterodyne signal detection has been attained. Field wind observations from the CW-Lidar are presented. The OPHIR CW-Lidar was operated at Stapleton Airport (Denver, CO) on an intermittent basis during the months of August and September 1990. The look angle of the device was up the landing glide-slope of an active runway. No wind shear events occured during our observation period. The 3.5 watt CW output power of our propotype sensor is shown to be marginal for achieving reliable sensor echo returns during clear air at Stapleton. When the air is filled with blowing dust or precipitation particles, echo spectra peaks of 10 to 30 db can be observed and velocity resolved. The best way to increase sensitivity of our proof-of-concept prototype further is by changing from our single-channel scanning spectral analyzer to a FFT or multi-channel spectral analyzer. A multiplex advantage of 500X should result, improving sensitivity by 13.5 db with the same integration time. The proof-of-concept prototype is difficult to maintain in optical alignment, and would require significant redesign to become airworthy. A more practical near-term utilization may be in ground based use at secondary airports to monitor possible wind shear hazards.

The final two viewgraphs, presented for related general interest, illustrate a new commercial capability to monitor supercooled water aircraft icing conditions above airports. Our subsidiary (Radiometrics Corporation) markets a millimeter wave device which can be used to remotely monitor aircraft icing conditions. We detected and quantified such conditions at the time of the Stapleton AP icing related crash of the Federal Express Cessna 208 N80FE at 0240Z on Feb 27, 1990. Our data set has been presented to the NTSB for use in their investigation.

1. DISCUSSION - VIEWGRAPH 1

This viewgraph briefing will discuss the development and field testing of a cost-effective heterodyne continuous wave (CW) wind-shear doppler lidar. The CW output power is 3.5 watts at 10.6μ through an 8" telescope.

This research was sponsored by the FAA under their SBIR Contract Number DTRS-57-87-C-00111.

We will discuss proof-of-concept prototype hardware design, field testing at Stapleton AP, and conclusions drawn from the research.

AIRBORNE WIND SHEAR REVIEW
NASA LANGLEY RESEARCH CENTER
OCTOBER 17, 1990

CW LASER FOR WIND SHEAR DETECTION

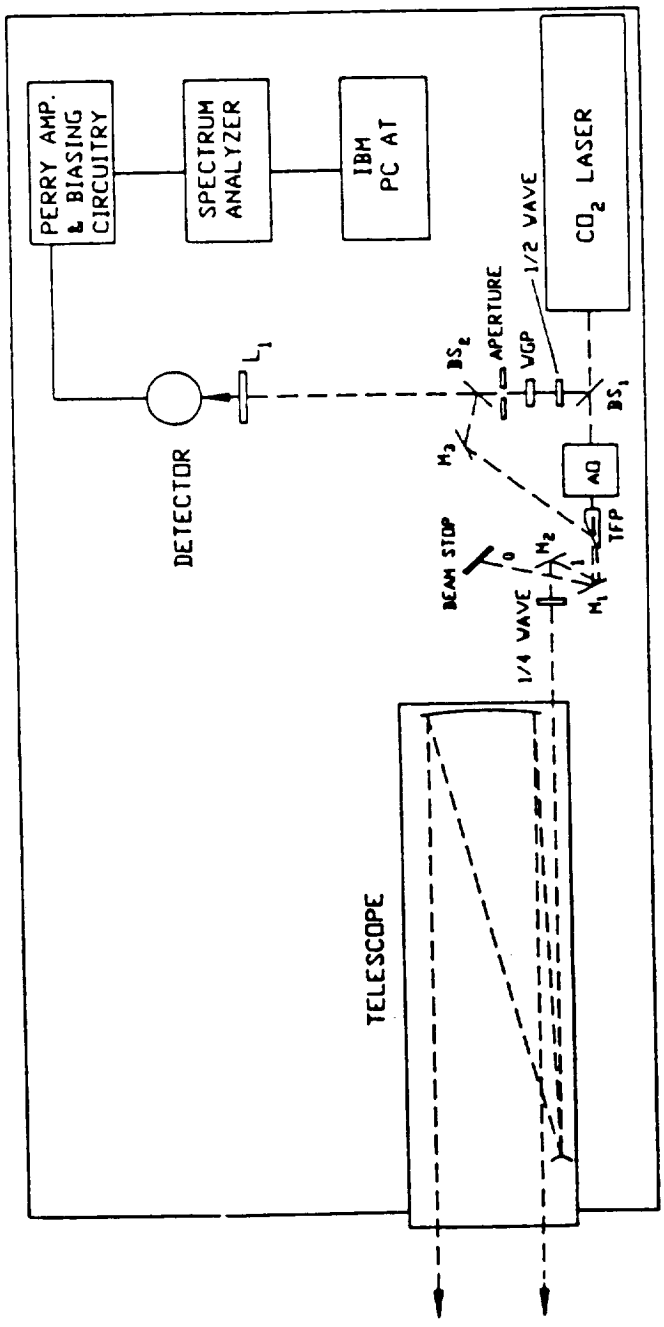
- Dr. Loren Nelson
- OPHIR Corporation
- 3190 S. Wadsworth Blvd.
- Lakewood, CO 80227
- (303) 986-1512

FAA SBIR CONTRACT NO. DTRS-57-87-C-00111

- Prototype Hardware Design
- Field Testing (Stapleton AP)
- Conclusions

2. DISCUSSION - VIEWGRAPH 2

A functional diagram of the CW heterodyne lidar is shown. By using an acousto-optic modulator at 27.1 Mhz offset, we can see wind both toward and away from the lidar in this heterodyne system. The detector is a liquid nitrogen cooled Mercury Cadmium Telluride photovoltiac sensor. The spectrum analyzer is a commercial single-scanning channel spectrum analyzer. Sweep time is 0.2 seconds, and 5 sweeps are averaged before display. There are 500 digitized data records written to disk during each sweep. Sweep length is +/- 3.7 Mhz, centered on 27.1 Mhz. This corresponds to a velocity range of +/- 10 m/s. Some runs were also made at a velocity range of +/- 25 m/s.

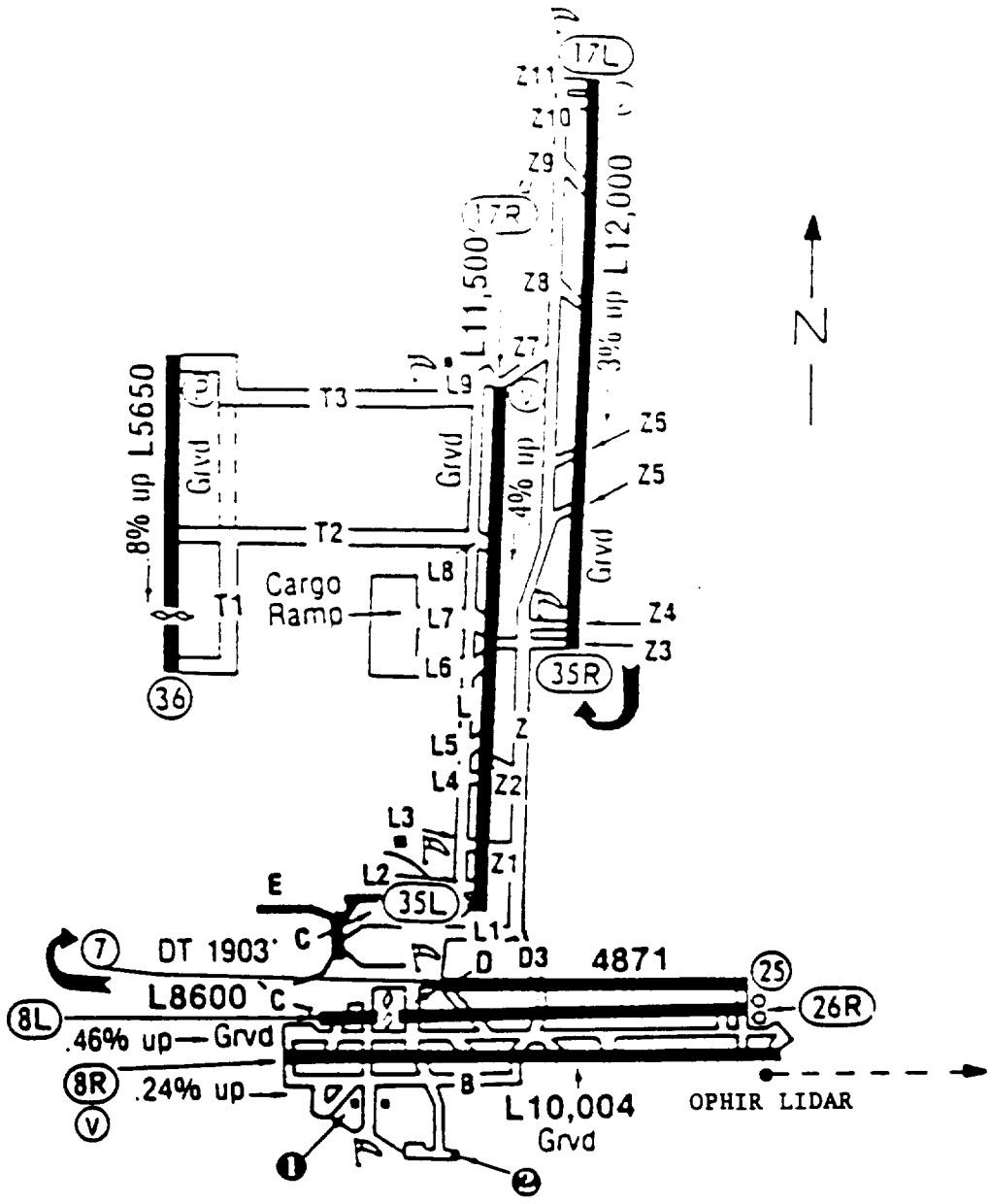

PERRY AMP. & BIASING CIRCUITRY
SPECTRUM ANALYZER
IBM PC AT
CO_2 LASER
1/2 VAVE
APERTURE
VGP
BS_2
BS_1
L_1
DETECTOR
M_3
AO
TFP
BEAM STOP
M_2
M_1
1/4 VAVE
TELESCOPE

3. DISCUSSION - VIEWGRAPH 3

Illustrates the location and orientation of the lidar van and beam during tests at Stapleton AP.

OPHIR CW WIND-SHEAR LIDAR

- LOCATION DURING STAPLETON AP TESTS

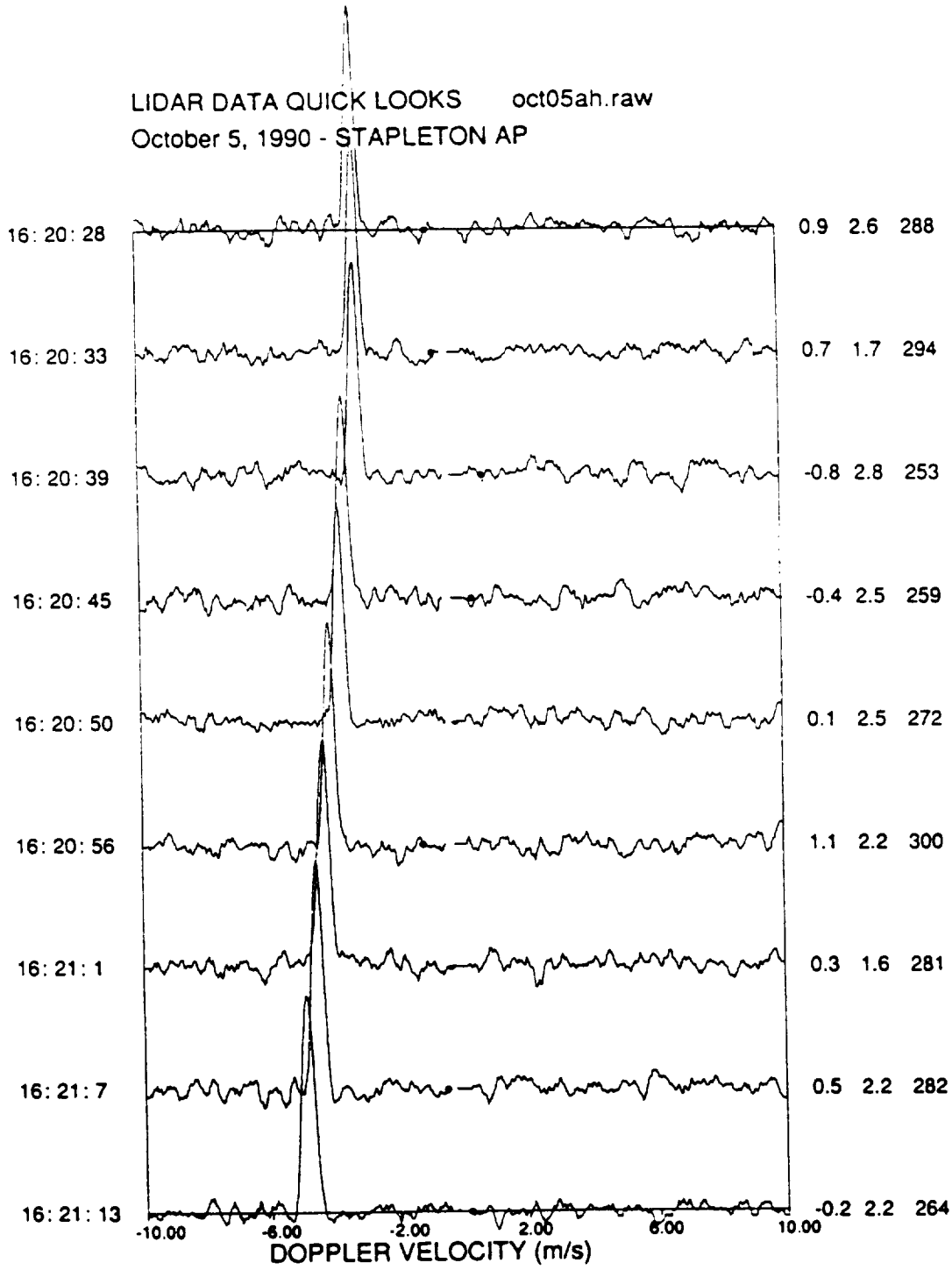


4. DISCUSSION - VIEWGRAPH 4

A color photograph of the Lidar Portable Van on location at Stapleton Airport.

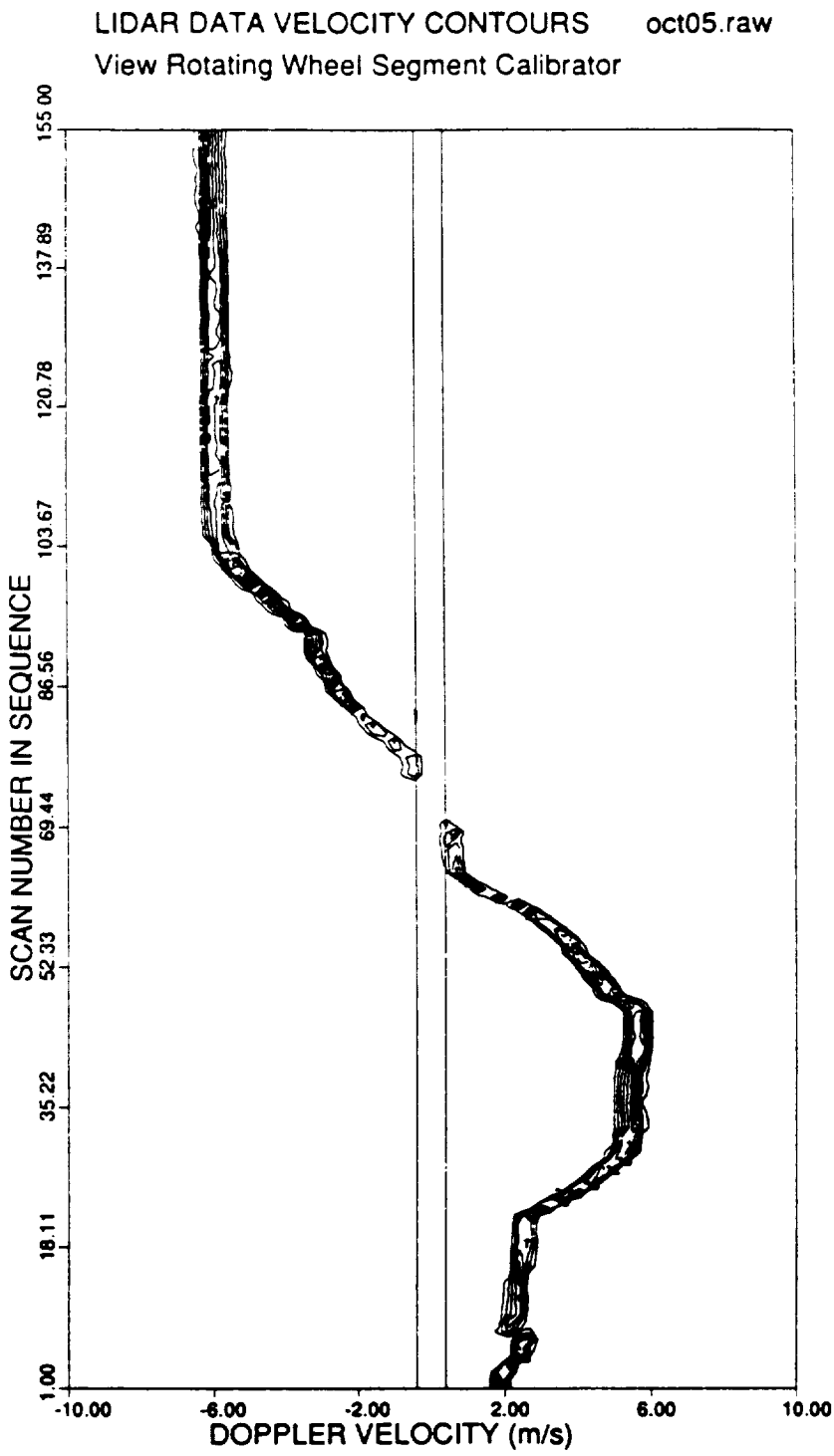
5. DISCUSSION - VIEWGRAPH 5

Data from functionality testing of the Lidar at Stapleton AP. Each successive trace is a 500 point spectrum analyzer scan of a +/- 10 m/s velocity range. Traces are separated vertically by 10 db. The lidar is viewing a segment of a rotating wheel calibrator about 100 yards away. As the wheel speed is changed, the location of the velocity spectral peak moves with it.


LIDAR DATA QUICK LOOKS oct05ah.raw
October 5, 1990 - STAPLETON AP
16: 20: 28
0.9 2.6 288
16: 20: 33
0.7 1.7 294
16: 20: 39
-0.8 2.8 253
16: 20: 45
-0.4 2.5 259
16: 20: 50
0.1 2.5 272
16: 20: 56
1.1 2.2 300
16: 21: 1
0.3 1.6 281
16: 21: 7
0.5 2.2 282
16: 21: 13
-0.2 2.2 264
-10.00
-6.00
-2.00
2.00
6.00
10.00
DOPPLER VELOCITY (m/s)

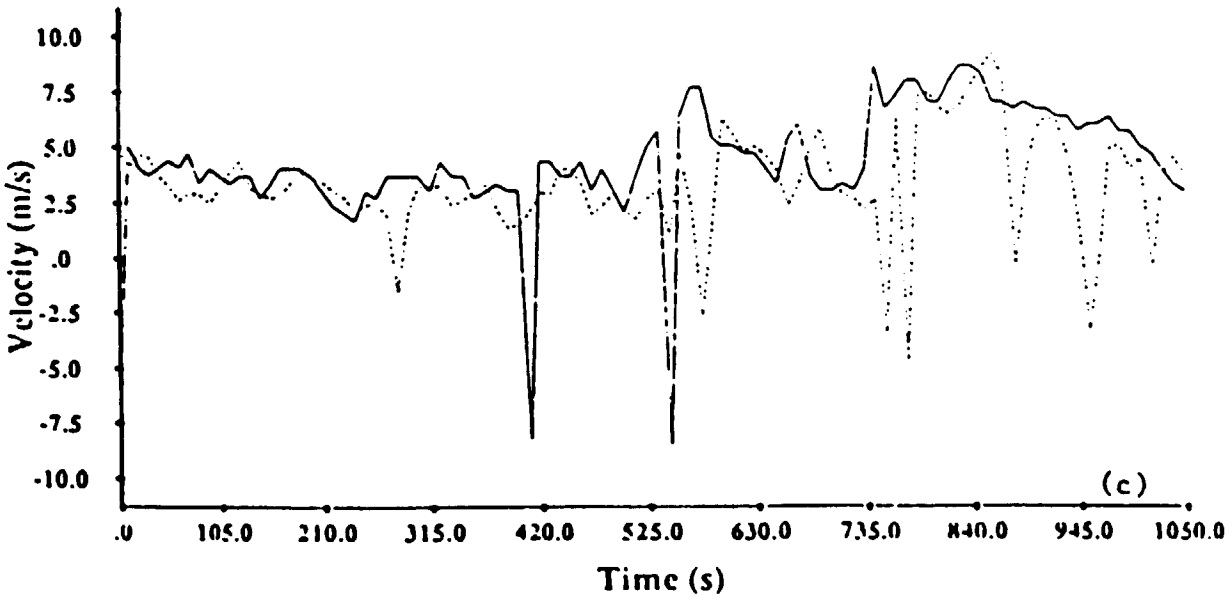
6. DISCUSSION - VIEWGRAPH 6

A larger portion of this same calibration wheel experiment. Spectral intensity is contoured showing the changing wheel velocity both toward and away from the lidar. The central section blanked out is not observable with this system due to zero velocity stray light and modulator noise pickup.


LIDAR DATA VELOCITY CONTOURS oct05.raw
View Rotating Wheel Segment Calibrator
SCAN NUMBER IN SEQUENCE
155.00
137.89
120.78
103.67
86.56
69.44
52.33
35.22
18.11
1.00
-10.00
-6.00
-2.00
2.00
6.00
10.00
DOPPLER VELOCITY (m/s)

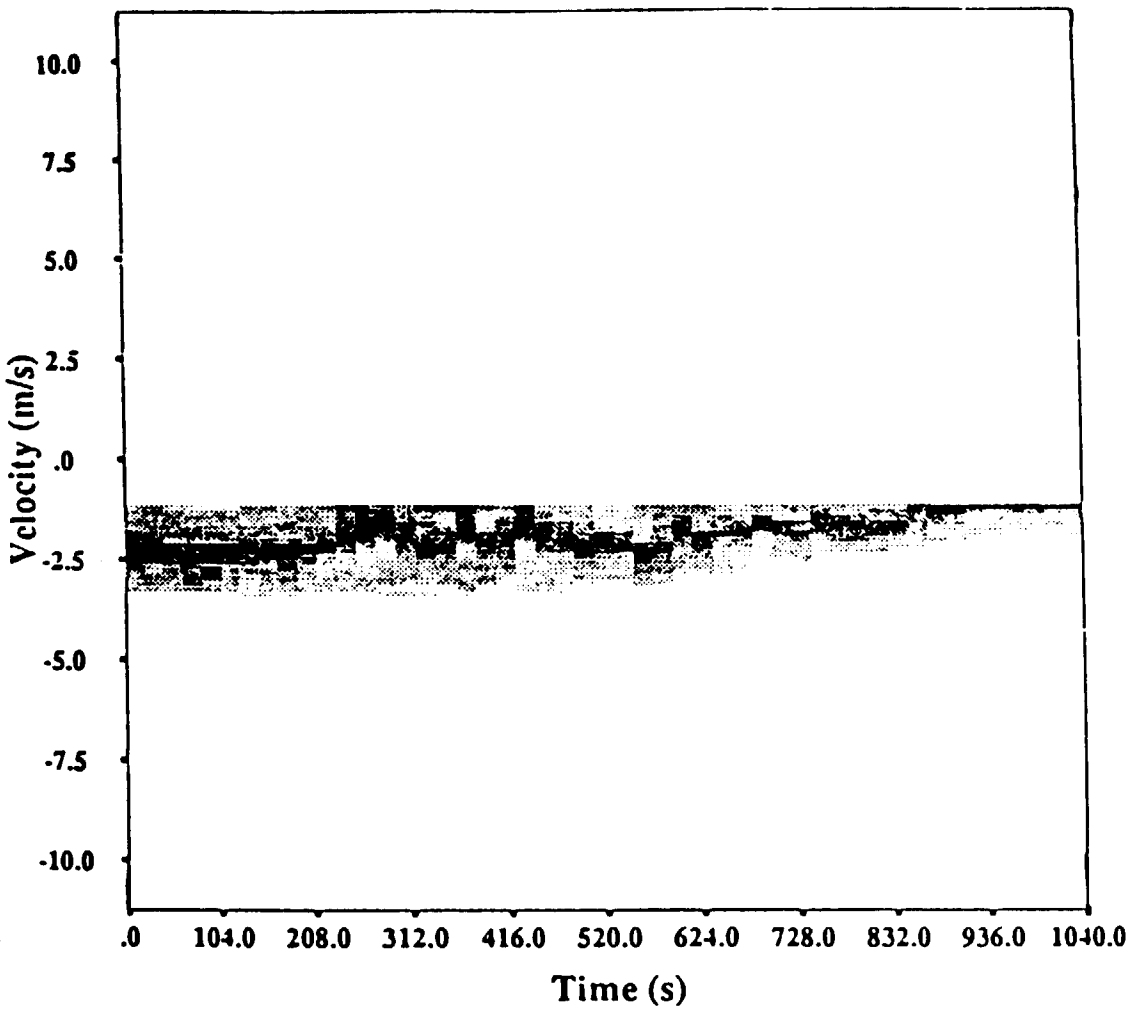
7. DISCUSSION - VIEWGRAPH 7

A comparion of lidar monitored wind velocity (solid) as compared to the along-beam wind component of a co-located anemometer (dashed).


10.0
7.5
5.0
2.5
.0
-2.5
-5.0
-7.5
-10.0
Velocity (m/s)
(c)
.0
105.0
210.0
315.0
420.0
525.0
630.0
735.0
840.0
945.0
1050.0
Time (s)

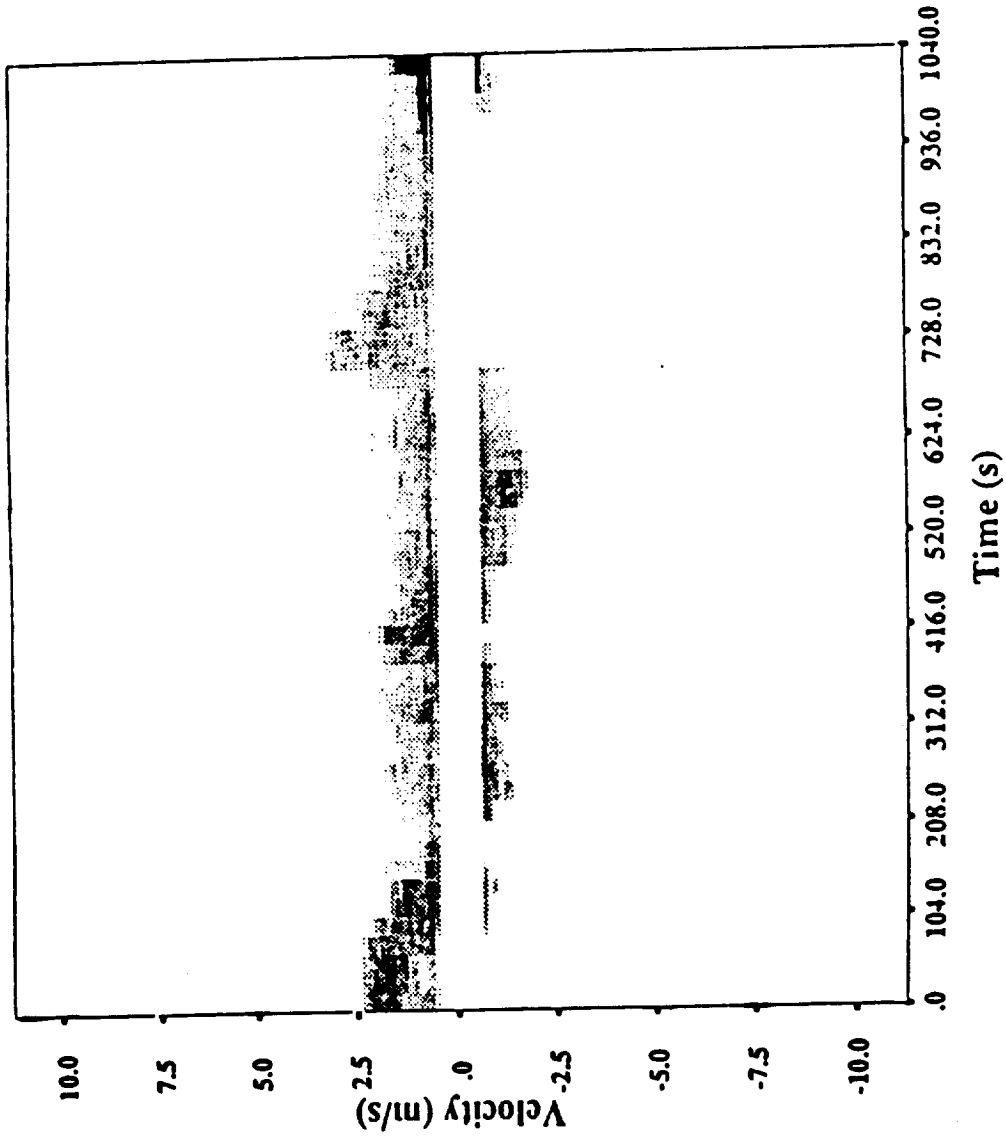
8. DISCUSSION - VIEWGRAPH 8

A sample spectral intensity gray scale plot of the lidar return from natural wind. The wind velocity changes from -2.5 m/s to zero during the course of the experiment.


10.0
7.5
5.0
2.5
.0
-2.5
-5.0
-7.5
-10.0
Velocity (m/s)
.0
104.0
208.0
312.0
416.0
520.0
624.0
728.0
832.0
936.0
1040.0
Time (s)

9. DISCUSSION - VIEWGRAPH 9

A similar plot showing light and meandering wind where velocity toward and away from the lidar was simultaneously observed within the beam length. This illustrates that the system can record wind shears if they occur within the beam.


Velocity (m/s)
10.0
7.5
5.0
2.5
0.
-2.5
-5.0
-7.5
-10.0
Time (s)
.0
104.0
208.0
312.0
416.0
520.0
624.0
728.0
832.0
936.0
1040.0

10. DISCUSSION - VIEWGRAPH 10

Conclusions drawn from this research effort.

CONCLUSIONS

- COST EFFECTIVE HARDWARE DEMONSTRATED
  - 3.5 watt CW 10.6μ output power
  - Wind can be remotely monitored
  - Divergent winds can be seen
- STAPLETON AP TESTS
  - Intermittent Testing Aug and Sept 1990
  - No wind shear events occured
  - Sensitivity marginal in clear air
  - Sensitivity adequate in dust or precipitation
- PROTOTYPE DESIGN STATUS
  - Proof-of-concept prototype is difficult to align, bulky
  - 13.5db signal processing sensitivity improvement possible
  - Airborne use requires significant redesign
  - Possible ground-based utility at secondary airports

11. DISCUSSION - VIEWGRAPH 11

The last two viewgraphs relate to a different meteorological sensor for airport safety use. They are presented very briefly here for general interest. Ophir's subsidiary corporation, Radiometrics Corporation, has developed and is now internationally marketing a millimeter wave radiometer that is useful in geodetic surveying, weather forecasting, and radio-astronomy. It can also be configured to be capable of monitoring aircraft icing conditions above airports.

Viewgraph 11 is a copy of an illustrative handout about the sensor.

RADIOMETRICS MICROWAVE WATER VAPOR RADIOMETER

If you are involved in precise geodetic measurement, meteorology, or long-baseline astronomy, you should be aware of the newly available RADIOMETRICS Corporation Microwave Water Vapor Radiometer. This commercially available, transportable instrument can be used in the following applications:

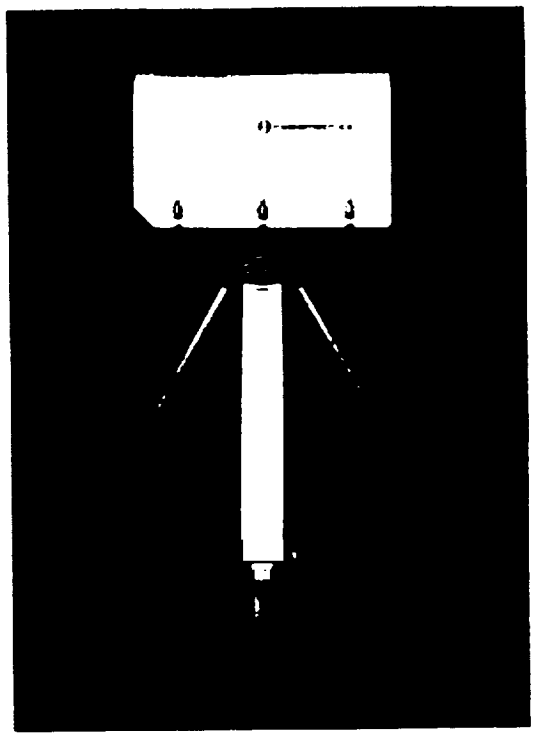
- Weather forecasting and modification
- Sea level measurement for climactic change
- Remote sensing of geophysical resources
- Measuring strains in the earth's surface and detecting plate tectonic motion
- Forecasting aircraft icing
- Very Long Baseline Interferometry (VLBI)

Standard output measurements include:

- Sky brightness temperature (degrees Kelvin)
- Total precipitable water (in millimeters)
- Total liquid water (in millimeters)
- Excess path length (vapor refractive error in centimeters)

Unique design features include:

- Fast start-up
- Quasi-optical lens components
- Low power requirements (17 watts)
- Internal noise diode calibration sources
- Gaussian Horn-Lens antenna (5° beam width)
- Sky brightness temperature accuracy of 0.5 K
- Mountable on standard surveying instrument tripod
- Complete internal autocalibration every 10 seconds
- Dual wavelength measurement (23.8 GHz and 31.4 GHz)
- Automatic elevation scanning along single selected azimuth
- Portability (15 kilograms in a 45×28×74 centimeter package)
- Internal microprocessor control for automated measurement



FUTURE DEVELOPMENTS

Plans include the addition of several passive 50-60 GHz oxygen channels to allow atmospheric temperature profiling as well as atmospheric moisture measurements from a single instrument package.

For more information concerning this instrument, please contact RADIOMETRICS Corporation at

3190 So. Wadsworth Blvd., Suite 100; Lakewood, Colorado 80227. U.S.A. Office hours are from 8:00 a.m. to 5:00 p.m. MST.

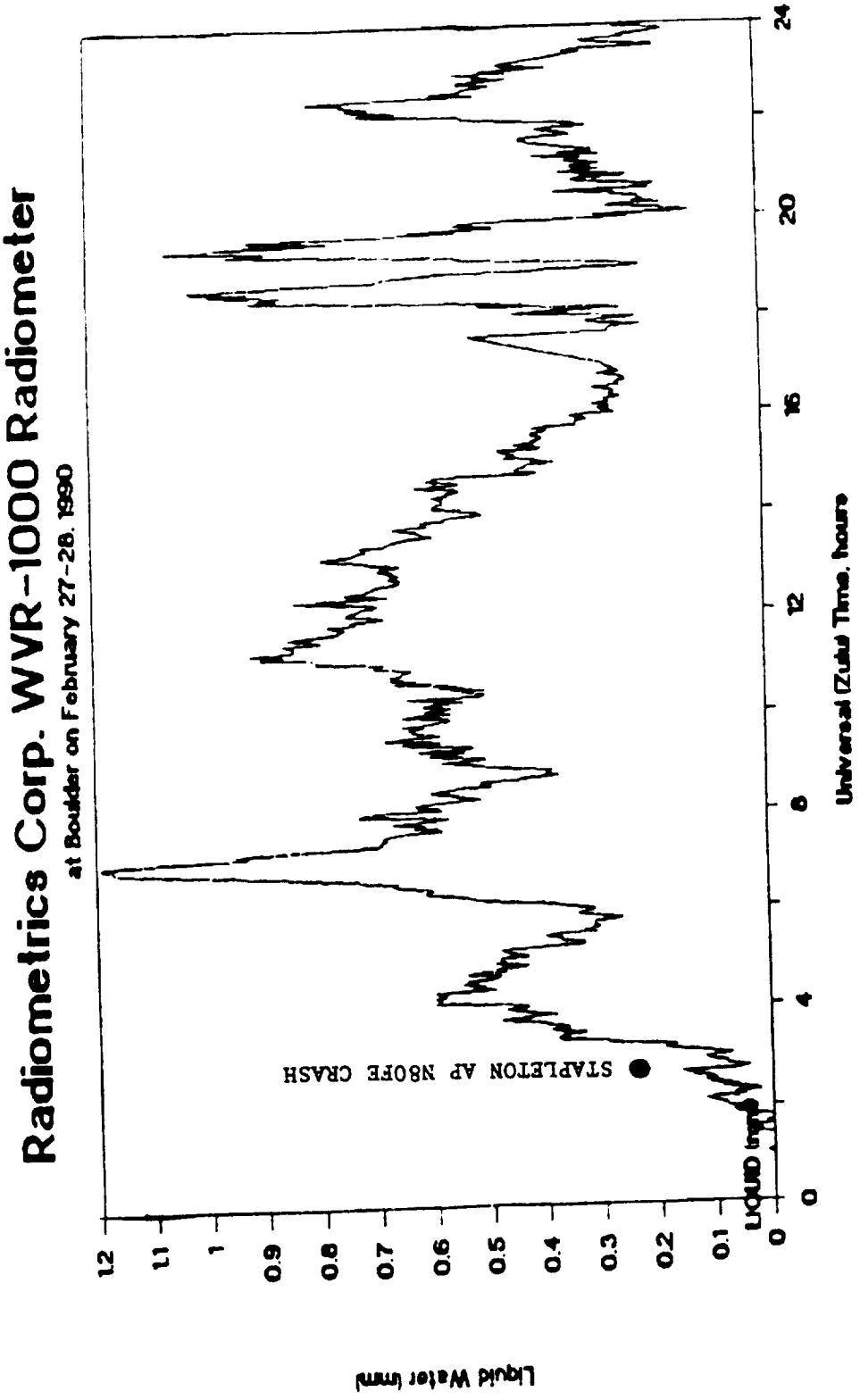
Telephone (303) 986-8558
24-Hour Telefax (303) 986-2257

radiometrics CORPORATION

12. DISCUSSION - VIEWGRAPH 12

On Feb 27, 1990 at 0240 Zulu the Federal Express Cessna 208 N80FE crashed upon landing at Stapleton in an icing related incident.

Radiometrics was operating its WVR-1000 Radiometer 30 miles away in Boulder, Colorado during this period of time. A data trace showing a time history of sensed supercooled liquid water amount (icing tendancy) aloft is shown. The time of the crash at Stapleton 30 miles away is shown as a dot. It can be seen that the crash occured at the beginning of a severe icing condition episode aloft as observed by the IR-2000. This data has been provided to the NTSB. We present it here for general interest since it may eventually prove to be a new method to monitor hazardous icing conditions aloft during aircraft airport approach and landing.



Continuous Wave Laser - Questions and Answers

Q: JACQUES MANDLE (SEXTANT Avionique) - What are the characteristics of your telescope; type and aperture; variable or fixed focussing distance?

A: LOREN NELSON (OPHIR Corporation) - The telescope was an off axis Doll-Kirkman telescope, 8 inches in aperture. That type was chosen in order to minimize the spicular reflection from the internal optical components of the scope. The focusing distance was adjustable manually between the range of 200 meters to infinity and the data you saw was taken at a setting of 500 meters.

Q: PETER SINCLAIR (Colorado State University) - With reference to the millimeter wave radiometer, what water vapor spectral line does the instrument employ and why was that frequency selected?

A: LOREN NELSON (OPHIR Corporation) - At the end of the presentation I briefly indicated that the Radiometrics WVR-1000 millimeter wave radiometer had detected an icing condition which was related to the February '90 Stapleton crash of an aircraft. Water vapor has a single purely rotational line at 23 GHz, the nearest closest line being at 183. We operate on the wings of the 23 GHz line, specifically at 23.8 GHz. That specific wave length was chosen for three reasons, one of which is, at that wave length the pressure dependence of the line broadening is altitude independent so we can use the same attenuation coefficient at all altitudes in the atmosphere. A second reason is by ICAO International Treaty, 23.8 GHz is an internationally protected band where nobody is allowed to radiate energy. Since we're looking at very weak emission on the order of 30 degrees Kelvin brightness temperature, that becomes important. And the third reason is, that 23.8 GHz has a specific relation to our second channel at 31.4 and that let's us use a patented technique to half the cost of the instrument. We measure at 23.8, which is a water vapor absorption line, we measure at 31.4, which is a water vapor window. Where there is a square law relation to the absorption of liquid water the two equations can then be solved to come out with the liquid water line interval and the water vapor line interval.

Q: GAUDY BEZOS (NASA Langley) - I am interested in more information on the sensor that measured the super-cooled liquid water content. How and where was the sensor mounted, was it at ground level? What were the liquid water content values measured?

A: LOREN NELSON (OPHIR Corporation) - The sensor happened to be at our research facility in Boulder, Colorado, which was 30 miles away from the Stapleton Airport. It was mounted at ground level looking vertically, in a vertical acceptance beam. The sensor is about the size of a large mailbox and mounts on a standard surveying tripod. It's also capable of scanning in azimuth and elevation. The values weren't purely liquid water content, but are precipitable liquid water. The liquid that would be obtained if all of the water in a vertical column was squished down to a liquid layer at the bottom. They were on the order of one centimeter of liquid water.